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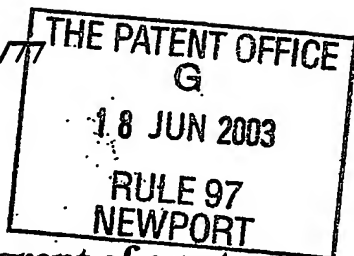
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Stephen Hordley

Dated

1 July 2004

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P01/7700 0-00-0314245.2

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1. Your reference

AA 1622 GB

0314245.2

2. Patent application number

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18 JUN 2003

3. Full name, address and postcode of the or of each applicant (underline all surnames)

JOHNSON MATTHEY PUBLIC LIMITED COMPANY  
2-4 COCKSPUR STREET  
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LONDON SW1 5BQ

Patents ADP number (if you know it)

If the applicant is a corporate body, give the country/state of its incorporation

GB

536268009

4. Title of the invention

ENGINE EXHAUST GAS TREATMENT

5. Name of your agent (if you have one)

ANDREW DOMINIC NUNN

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

JOHNSON MATTHEY TECHNOLOGY CENTRE  
BLOUNTS COURT  
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3951411001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (if you know it) the or each application number

Country

Priority application number  
(if you know it)

Date of filing  
(day / month / year)

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application

Date of filing  
(day / month / year)

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (Answer 'Yes' if:

YES

- a) any applicant named in part 3 is not an inventor, or
  - b) there is an inventor who is not named as an applicant, or
  - c) any named applicant is a corporate body.
- See note (d))

**Patents Form 1/77**

9. Enter the number of sheets for any of the following items you are filing with this form.  
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Continuation sheets of this form	0
Description	6
Claim(s)	2
Abstract	1
Drawing(s)	2 + 2 <i>ll</i>

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent ( <i>Patents Form 7/77</i> )	
Request for preliminary examination and search ( <i>Patents Form 9/77</i> )	ONE
Request for substantive examination ( <i>Patents Form 10/77</i> )	
Any other documents ( <i>please specify</i> )	

11.

I/We request the grant of a patent on the basis of this application.

Signature

*Ad Nunn*  
A D NUNN

Date 17/6/03

12. Name and daytime telephone number of person to contact in the United Kingdom

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ENGINE EXHAUST GAS TREATMENT

This invention relates to engine exhaust gas treatment, more particularly to removal of nitrogen oxides 'NOx' from the exhaust of a lean-burn reciprocating engine.

It has been proposed to remove such NOx by sorption in a basic oxidic material, then regenerating that material and concurrently converting NOx to N<sub>2</sub> with an agent which is a reductant or a NOx-specific reactant. This process is subject to the problem how to limit or avoid emission to atmosphere of such agent, which is commonly used in excess and thus is not 100% reacted.

In the ensuing description and claims: terms based on the word 'sorb' will be used to denote 'absorb' or 'adsorb' or any occurrence of both such processes; and metal compounds effective to sorb NOx will be referred as 'oxides', with the understanding that this term includes other oxidic compounds such as hydroxides and carbonates effective as NOx sorbents and present in the conditions of exhaust gas treatment.

According to the invention a lean-burn reciprocating engine emitting exhaust gas containing NOx and having a treatment system comprising a NOx sorber chargeable when the exhaust gas is lean and regenerable by intermittent contacting with an agent effective to convert NOx to N<sub>2</sub>: is **characterised by** feeding effluent of said contacting to the engine inlet.

The engine is preferably one equipped for exhaust gas recycle (EGR) in normal or occasional modes of operation. Alternatively an EGR system can be added to an engine not normally using EGR.

Since feeding the said effluent to the engine inlet is merely to dispose of the agent contained in it, its rate of flow is in principle not related to in-engine combustion requirements of conventional EGR. To permit complete recycle of the effluent without excessive EGR the system preferably includes a plurality of parallel NOx sorbers fewer than all of which are simultaneously contacted with said

agent. The flow rate of the gas in the sorber(s) under regeneration is preferably limited further, to be less than in the remaining sorber(s) and especially to be at or below the rate of recycle in an existing or added EGR system. Such system preferably includes an EGR pump, which determines the flow rate of the recycle effluent.

The agent is conveniently provided by injection into the gas about to enter the sorber to be contacted therewith. Reductant may be provided, in a multi-cylinder engine, by intermittently operating fewer than all, preferably one of, the cylinders at a rich or approximately neutral air-fuel ratio, and feeding the resulting exhaust to the sorber(s) to be regenerated.

The agent may be a non-selective reductant such as hydrocarbon, CO or hydrogen, injected as such or as compound(s), for example engine fuel, convertible thereto in regeneration conditions over the NO<sub>x</sub> sorbent or in a pre-injection step. In an engine having a common-rail fuel injection system there may be a branch to NO<sub>x</sub> sorber injectors. Non-selective reductant is evidently used if provided by rich/neutral operation of a cylinder.

Alternatively the agent may be NO<sub>x</sub>-specific, for example a nitrogen hydride such as ammonia or hydrazine, conveniently provided as a precursor such as an amide for example urea or ammonium carbamate, and possibly fed via a catalyst effective to generate the free hydride.

In addition to the NO<sub>x</sub> removal step the engine exhaust system may include: upstream of the NO<sub>x</sub> sorbers: catalytic oxidation of HC and CO to steam and CO<sub>2</sub> and/or of NO to NO<sub>2</sub>; PM collection preferably downstream of that catalytic oxidation. downstream of the NO<sub>x</sub> sorbers: catalytic oxidation of residual HC and CO; collection of PM passing the NO<sub>x</sub> sorbers or passing an upstream filter as a result of too small particle size or release by filter flow reversal.

When the system includes PM collection, the engine may be designed and calibrated to emit raw exhaust gas containing enough NO<sub>x</sub> to combust, after oxidation of NO to NO<sub>2</sub>, the whole carbonaceous fraction of said PM. Alternatively it

may be designed and calibrated to emit, at least temporarily, raw exhaust gas containing too little NO<sub>x</sub> to combust, after oxidation of NO to NO<sub>2</sub>. The PM collection means preferably comprises a catalyst effective to promote said combustion and possibly also an oxygen storage material. In each combustion procedure the temperature is at or above the 'balance temperature' continuously or at intervals when PM has accumulated to a design level. If PM collection uses a filter, provision may be made for intermittent reversal of flow direction therethrough. The engine control system may provide for operation at an inlet air fuel ratio strongly lean for normal running but moderately lean when the temperature is increased for combustion of PM by oxygen.

The NO<sub>x</sub> sorbent is typically selected from :

- (a) oxides of alkali-, alkaline earth-, rare earth- and transition-, metals capable of forming nitroxy salts of adequate stability in sorbing conditions and of releasing /reacting nitrogen oxides in regenerating conditions.
- (b) adsorptive materials such as zeolites, carbons and high-area oxides.

Whichever compounds are used, there is preferably present one or more catalytic materials such as precious metals, especially Pt+Rh, effective to promote reaction of NO<sub>x</sub> with reductant or NO<sub>x</sub>-specific reactant.

The sorbent(s) and catalyst(s) are suitably on throughflow monolithic substrates composed of ceramic, wound corrugated metal, or metal foam or sintered or ordered or random-packed wire or flat wire. Filters, if used, may use substrates similar to those of sorbents and catalysts, but in 'filter-grade' permeable to gas and having limited permeability to PM.

To switch gas flow successively from NO<sub>x</sub> sorbers in use and under regeneration the system suitably includes a valve comprising: an outer cylindrical or frusto-conical casing formed with angularly spaced apertures each leading to an external flow connections; a barrel fitting fluid-tightly within the casing and rotatable on an axis transverse to the main direction of fluid flow; formed along each of 2 or more radial planes of the barrel at least one fluidtight dividing member; and formed

in each division at least one passage open at mutually angled positions about the circumference of the barrel, said positions corresponding to the apertures.

The barrel can be provided by uniting sheet material to define its outer shape and internal passages or by shaping solid material and forming the passages by boring therinto, so that the residues between bores constitute the dividing members. Each passage normally has an outlet angled to its inlet, for example perpendicularly in a 4-way valve with one inlet connection and 2 or 3 outlet connections. In a 4-way valve having 2 inlet connections and 2 outlet connections, each passage may have 1 inlet and 2 outlets.

The invention is illustrated by the accompanying drawings, in which:

Figure 1 is a flowsheet showing an exhaust gas treatment system in which the valve is used to provide switching flow between 2 NO<sub>x</sub> sorbers; and

Figure 2 is a flowsheet showing an exhaust gas treatment system in which also the valve in a variant is used to provide flow-reversal through a PM filter;

Referring to Fig 1, in diesel engine 10 the inlet system comprises fuel feed 12, air feed 14 and exhaust gas recycle (EGR) feed 16, and exhaust gas passes out through manifold 18 to reactor 20 containing oxidation catalyst 22 consisting of a ceramic honeycomb carrying a washcoat and Pt, followed by PM filter 24. Filter 24 consists of a filter-grade ceramic honeycomb the passages of which are alternately open and closed at the inlet end and, corresponding to the inlet open passages, alternately closed at the outlet end. It may carry a catalyst for soot oxidation, for example Pt or La/Cs/V<sub>2</sub>O<sub>5</sub>. The downstream end of reactor 20 is provided with outlets 26 leading respectively to NO<sub>x</sub> sorbers 30A and 30B, each of which holds a ceramic honeycomb unit carrying an alumina washcoat containing metallic Pt+Rh and barium oxide. Sorbers 30A,B may be provided in separate cans as shown or, to save space, may be in fluid-tight subdivisions of a single can. Each sorber 30A,B is equipped with an injector 32A,B for hydrocarbon from the common-rail system of the engine (connection not shown), or of ammonia or precursor thereof.

Each outlet end of sorbers 30A,B. is connected to one of the 2 inlets of 4-way valve 28, whose outlets 34 to the EGR inlet 16 (via a pump, not shown) and 36 to atmosphere align with one or other of the outlets of within-barrel T-shaped passages indicated by arrows. Valve 28 is operable between 3 positions 28X, 28Y and 28Z (Y and Z insets).

[ NOTE: the 2 divisions of the valve barrel are referred to as 'LHS' i e left hand side and 'RHS' i e right hand side, but this is for convenience in understanding the drawings and is not intended to indicate practical construction]

In position X both sorbers and both outlets are open: consequently there is no blocked midpoint.

In position Y the root of the LHS T-shaped passage is open to gas leaving sorber 30A, but only one arm of the 'T' is open, the other being aligned with the valve housing between outlets; consequently there is gas flow only to 34 at the inlet rating of the EGR pump. At the same time the root of the RHS T-shaped passage is open to gas leaving sorber 30B, but only the one arm of the 'T' is open, the other being aligned with the valve housing between outlets; consequently there is no flow to EGR, and the whole effluent of 30B passes out via 36.

In position Z operation is analogous, feeding the effluent of 30B to EGR and 30A out.via 36.

In normal operation of the engine the exhaust gas, comprising steam,  $N_2$ ,  $O_2$ ,  $CO_2$ , HC, CO,  $NO_x$  and PM, at e g 300C contacts catalyst 22 over which NO is oxidised to  $NO_2$  and some of the HC and CO are oxidised to steam and  $CO_2$ . It then enters filter 24 on which most of the PM is collected and combusted by reaction with the  $NO_2$  formed in catalyst 24 and possibly also with  $O_2$ . The PM-freed gas then undergoes treatment in one of the 3 modes: 28X: sorbers 30A and 30B each sorb  $NO_x$  from half the total gas flowing; sorber outlet gas passes mainly to atmosphere or further treatment at 36, partly to EGR at 34 at the flow rating of the EGR pump not shown; 28Y: sorber 30A receives a fraction, corresponding to the EGR pump rating, of the total gas flowing and also HC or ammonia injected at 32A. It undergoes



regeneration and its effluent is fed to EGR at 34; sorber 30B sorbs NO<sub>x</sub> from a large fraction of the total gas flowing and its effluent passes to atmosphere or further treatment at 36; 28Z: sorbers 30B and 30A exchange the duties performed at 28Y. The engine management system (not shown) changes from 28X to 28Y or the reverse when the sorber not about to be regenerated is substantially charged with NO<sub>x</sub> but has enough NO<sub>x</sub> sorption capacity in hand to treat the large fraction of the total gas during the regeneration period.

Referring to figure 2, items 10-18 are the same as in fig 1 and are indicated schematically. Reactor 20 now contains only catalyst 22. The PM filter, now numbered 25, is in separate vessel 21. It differs in providing for reversal of the direction of flow through the filter. The outlet of reactor 20 is connected to filter vessel 21 by way of single-inlet reversing valve 23, operable in positions 23A and 23B (inset), to give respectively RH to LH or LH to RH flow through filter 25. Leaving filter 25 in either direction, the gas passes through valve 23A or B to a bifurcation into outlets 27, each leading to NO<sub>x</sub> sorber 30A or 30B and downstream 4-way valve 28. Operation of valve 28 is the same as in figure 1, except that outlet 36 to atmosphere is replaced by connection 37 to vessel 38 holding filter 40, the duty of which is to collect PM released from filter 25. Such PM is typically ash, in which event filter 40 may be disposable, such as fibre or paper. Another duty of filter 40 can be to collect any ultra-fine combustible PM not collected by filter 25

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CLAIMS

1. A lean-burn reciprocating engine emitting exhaust gas containing NO<sub>x</sub> and having a treatment system comprising a NO<sub>x</sub> sorbent chargeable when the exhaust gas is lean and regenerable by intermittent contacting with an agent effective to convert NO<sub>x</sub> to N<sub>2</sub>: **characterised by** feeding effluent of said contacting to the engine inlet.
2. Engine according to claim 1 equipped for exhaust gas recycle (EGR) in normal or occasional modes of operation.
3. Engine according to claim 1 or claim 2 having a plurality of parallel NO<sub>x</sub> sorbers fewer than all of which are simultaneously contacted with said agent.
4. Engine according to claim 3 in which the gas flow in the sorber(s) under regeneration is less than in the other sorber(s) and substantially the whole of the effluent of the sorber(s) under regeneration is fed to the engine inlet.
5. Engine according to claim 4 in which the system includes an EGR pump.
6. Engine according to any one of the preceding claims in which the agent is provided by injection into the gas about to enter the sorber(s) under regeneration
7. Engine according to any one of the preceding claims in which the agent is a non-selective reductant such as hydrocarbon, CO or hydrogen.
8. Engine according to claim 7 in which the agent is engine fuel.
9. Engine according to claim 8 having a common-rail fuel injection system with a branch to NO<sub>x</sub> sorber injectors.
10. Engine according to any one of claims 1 to 6 in which the agent is a nitrogen hydride.

11. Engine according to any one of the preceding claims in which the system includes, upstream of the NOx sorber(s), catalytic oxidation of HC and CO to steam and CO<sub>2</sub> and/or of NO to NO<sub>2</sub>.

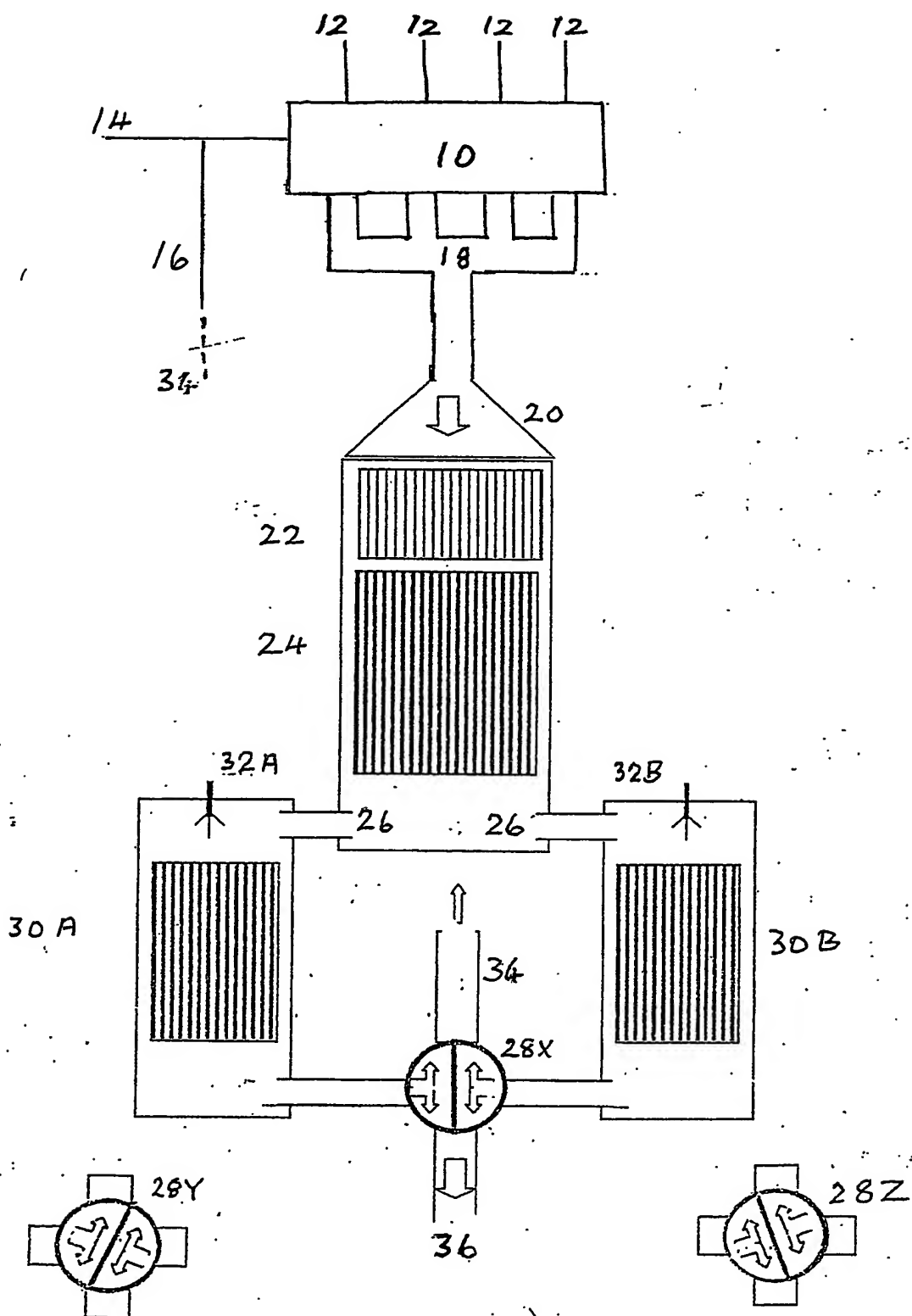
12. Engine according to claim 11 in which the system includes PM collection downstream of NO oxidation but upstream of the NOx sorber(s).

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**ENGINE EXHAUST GAS TREATMENT****Abstract**

A lean-burn reciprocating engine comprises a  $\text{NO}_x$  sorbent (30A; 30B) chargeable when the exhaust gas is lean and regenerable by intermittently contacting it with an agent effective to convert  $\text{NO}_x$  to  $\text{N}_2$ , the arrangement being such that exhaust gas containing said agent is fed to the engine inlet (14).

[Figure 1]

1/2  
FIGURE 1

2/2  
FIGURE 2